**Original Research Article**

**DEVELOPMENT OF LOCAL VOLUME TABLE FOR *Pinus caribbaea* var. *hondurensis* (Senecl) IN AREA J4, OMO FOREST RESERVE, NIGERIA**

# ABSTRACT

Volume estimation is a very vital part of every forest or plantation because it gives the quantity of timber or wood available at a given period and also predicts future or expected growth of the forest. Unfortunately, local volume table are not readily available for some economic tree species in Nigeria. Hence, it is of paramount importance that local volume table be developed for economic tree species such as *Pinus caribbaea* in area J4, Omo Forest reserve, Ogun state, Nigeria.

**Aim**: The aim of this study is to develop a local volume table for *Pinus caribbaea* in area J4, Omo Forest reserve, Ogun state, Nigeria.

**Study designs**: Simple random sampling was used for this study. Ten Temporary Sample Plots (TSP) of equal size 25m x 25m were randomly located in the selected plantation (*P. caribbaea*: established in 1997). All trees with diameter at breast height (dbh) ≥ 10cm in each TSP were enumerated.

**Place and duration of Study**: The study was carried out in the *Pinus caribbaea* plantation in area J4, Omo forest reserve, Ogun state from November 9th to 20th, 2023.

**Methodology**: The tree total height, merchantable height, Diameters at the top, middle, base, and dbh were measured and used to estimate stand volume. Volume table was developed using five selected models and the best model was selected using least Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Root Mean Square Error (RMSE). Data was analyzed using descriptive statistics and regression at α0.05 with R statistical software.

**Results**: The results obtained in *P. caribbaea* plantation revealed that the dbh and height were 27.93±6.95cm and 28.72±3.47m, respectively while individual tree volume was 0.83±0.57m3. The combined variable model ($V\_{i}=-9.857e-02+3.851e-05D\_{i}^{2}H\_{i}+ε\_{i})$ was selected as the best model to develop local volume table for *P. caribbaea* (AIC = -54.73, BIC = -45.49 and RMSE = 0.20).

**Conclusion:** The volume table developed will be useful in giving an estimate of the quantity of wood or timber available in the *Pinus Caribaea* plantation at a given time. The volume model and local volume table developed are to be applied on the *Pinus caribaea* plantation in the study area only.

***Keywords****: Volume table, Volume models, None-destructive sampling, Pinus caribbaea Plantation*

**1. INTRODUCTION**

Forest inventory serves as a very important tool in forest management; it provides the data for planning, monitoring, evaluation, research, growth and yield and timber sale. The current level of the growing stock can be obtained through forest inventories and the future growth can be accessed from a current inventory by using growth and yield models [1]. Volume estimation is a very vital part of every forest or plantation because it gives the quantity of timber or wood available at a given period and also predicts future or expected growth of the forest. Wood volume estimation has been a central research topic in forest science because accurate estimates of wood volume are essential in sustainable forest management and for trade in forest resources [2]. For inventory and management purposes, the forest manager or researcher must be able to determine the volume quickly for standing trees and even after the trees are being harvested. Volume table is a tabular statement showing the volume with respect to diameter of specific area. Globally, volume table keeps a significant role for volume calculation of standing trees [3; 4].

*Pinus caribbaea* is a durable and easily workable softwood widely used for construction, engineering, and decorative purposes. In tropical countries, the need for long-fiber wood for the building and paper industries has made *P. caribbaea* a suitable species for global level and aggressive reforestation program that not only restores the losses but also attempts to increase the surface under vegetation and reduce desert and semi deserted areas of the world. To this end the Caribbean pine has been suc­cessfully used in reforestation programs in several parts of the world. Research have shown that volume tables have been developed for *P. caribeae* in BuloloWau Forest plantations New Guinea [5] also Volume equations and tables have been developed for some species [e.g. 6; 7] but no volume table have been developed for *P. caribaea* in Area J4, Omo Forest reserve. The main objective of this study is to develop local volume table for *Pinus caribbaea* in area J4, Omo Forest reserve, Ogun state.

**2. MATERIALS AND METHOD**

**2.1 Study Area**

The study was carried out on the available age series of *Pinus carribaea* plantation at Area J4, Ijebu- Ode, Ogun State. It is located between latitudes 6°35' to 7°05' N and longitudes 4°19' to 4°40' E in the South-west of Nigeria (Fig 1) and covers an area of 130,500 hectares [8]. It is about 135 km North-East of Lagos, about 120 km East of Abeokuta and about 80 km East of Ijebu-Ode [9]. The reserve shares a common boundary in its Northern part with two other forest reserves – Ago Owu and Shasha in Osun state. It also has a common Eastern boundary with Oluwa Forest Reserve in Ondo state [10]. The mean annual rainfall ranges from about 1600 to 2000 mm with two annual peaks in June and September, with November and February being the driest months [11;12].

Figure 1Omo Forest Reserve showing the study area. Source: [13]

**2.2 Species Description**

*Pinus caribaea* var. *Hondurensis* (Senecl) Barr.et Golf. is widely grown in the African tropics and subtropics [14]. In its natural habitat in central America and the Caribbean Basin, *Pinus caribaea* performs best at low altitudes (approximately 700 m asl) and on fertile, well-drained soils with mean annual rainfall (MAR) of 1200 mm per year and mean annual temperatures ranging from 20°Cto 27°C [15]. In Africa, *Pinus caribaea* is reported to be adaptable to a wide range of climates and elevations [16; 17]. The hard wood of *Pinus caribaea* is appropriate for floors and all types of construction.

# 2.3 Sampling Procedure

Simple random sampling was used in this study. *P. caribbea* plantation stand of 1997 was purposively selected for this study base on availability and relatively low disturbance/harvesting. Volume table development for this age series was needed because they are mature to meet management objectives (timber production). Hence, the management of the forest reserve will need the table for valuation purpose during allocation processes. Ten Temporary Sample Plots (TSP) of equal size 25 m x 25 m were randomly located in each of the plantation.

# 2.4 Method of Data Collection

All trees in each Temporary Sample Plot (TSP) were enumerated. The tree total height, merchantable height, Diameter at the top (Dt), Diameter at the middle (Dm), Diameter at the base (Db), and Diameter at Breast Height (dbh) over bark at 1.3m above the ground of all trees encountered in a sample plot were measured using diameter tape and Height was measured using Spiegel relaskop.

# 2.5 Data Analysis

#### **2.5.1 Volume Estimation**

The volume of all trees in the sample plots was calculated using Newton’s formula.

$V=π\frac{H}{24}\left(D\_{b}^{2}+4D\_{m}^{2}+D\_{t}^{2}\right)$ …………………… Eq.1

Where,

V= volume (m3)

$D\_{b}$ = the sectional area at the base (m2)

$D\_{m}$ = the sectional area at the middle (m2)

$D\_{t}$ = the sectional area at the top (m2)

**2.5.2 Development of Local Volume Tables**

For the development of local volume table, the non-destructive method was used. Five (5) volume equations such as the constant form factor, combined variable, logarithmic, Generalized combined variable and Generalized logarithmic were used (Table 1).

Table 1 Selected Local Volume Equations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S/N** | **MODEL NAME** | **FORMULA** | **REFERENCE** |  |
| 1 | Combined variable | $V\_{i}=b\_{0}+b\_{1}D\_{i}^{2}H\_{i}+ε\_{i}$  | [18]  |  |
| 2 | Constant form factor | $V\_{i}=b\_{1}D\_{i}^{2}H\_{i}+ε\_{i}$  | [18] |  |
| 3 | Logarithmic  | $V\_{i}=e^{b1}D\_{i}^{b2}H\_{i}^{b3}e^{ε\_{i}}$  | [18] |  |
| 4 | Gen. combined variable | $V\_{i}=b\_{0}+b\_{1}D\_{i}^{2}+b\_{2}H\_{i}+b\_{3}D\_{i}^{2}H\_{i}+ε\_{i}$  | [18] |  |
| 5 | Generalized logarithmic | $V\_{i}=b\_{0}+b\_{1}D\_{i}^{b2}H\_{i}^{b3}e^{ε\_{i}}$  | [18] |  |

**Note:** $V\_{i}$- Individual tree stem volume, Di- Individual tree diameter at breast height, Hi- Individual tree total height, b0, b1, b2 and b3- Regression parameters, e- Exponential function, $ε\_{i}$- Error term. Gen-Generalized

# 2.5.3 Model Evaluation

Akaike information criterion (AIC), Bayesian information criterion (BIC) and Root mean square error (RMSE) were used as the evaluation indices. Models with the least AIC, BIC and RMSE were selected as the best.

$AIC=ln\left(\frac{RSS}{n-k}\right)+\frac{2}{n}K$ ………………………………….. Eq. 2

$BIC=ln\left(\frac{RSS}{n-k}\right)+\frac{k}{n}ln\left(n\right)$ ……………………………….…. Eq. 3

$RMSE=\sqrt{\frac{\sum\_{}^{}(y\_{i}-\hat{y}\_{i})^{2}}{n}}$ …………………………………… Eq. 4

Where,

$ln$= Natural logarithm

$RSS=$ Residual sum of squares

$n =$Total number of observations

K= Number of independent variables

$y\_{i}$ = Observed values of y

$\hat{y}\_{i}$ = Predicted values of y

**3. RESULTS AND DISCUSSION**

Table 2 revealed the summary of the descriptive statistics of the different tree growth variables obtained and calculated for *Pinus caribbaea* plantation in Area J4, Omo Forest reserve. According to the result, diameter at breast height (dbh, cm) has mean of 27.93±6.95, minimum and maximum values are 16.2 and 52, respectively. For total height (H, m), mean value is 28.72±3.47, minimum and maximum heights are 10.6 and 33.2, respectively. The Basal Area (BA, m2) has the mean of 0.065±0.03, minimum and maximum values of 0.021 and 0.212, respectively. The mean volume is 0.832±0.57, minimum and maximum volumes are 0.088 and 3.28, respectively. The established relationship between dbh and stem height (Figure 2) shows that there was positive linear relationship. This is typical of tropical plantation forest [3]. Also, it is evident that all the selected trees used in this study tend to follow similar trend of tapering from bottom to the top, which confirms the biological validity of the data set as indicated by [3].

Table 2 Summary Statistics for *Pinus caribbaea*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Growth variable** | **Mean** | **Min**  | **Max**  | **Standard deviation** |
| **Dbh** | 27.93 | 16.2 | 52 | 6.95 |
| **H** | 28.716 | 10.6 | 33.2 | 3.474 |
| **BA** | 0.065 | 0.021 | 0.212 | 0.033 |
| **V** | 0.832 | 0.088 | 3.284 | 0.571 |

Dbh=diameter at breast height, H=total height, BA=basal area, V= volume

Figure 2 relationship between total height and diameter at breast height

Table 2 shows the summary of the five (5) volume models used for *Pinus caribbaea* plantation in the study area. According to the result, the Combined variable has the best fit with the least values for two (2) of the fitting indices which are AIC (-54.73395), BIC (-45.48974) and RMSE (0.2016). The next best fit is the Generalized combined variable (GCV) and Generalized logarithmic the Combined variable with AIC (-54.09115), BIC (-38.68413) and RMSE (0.2008), followed by Logarithmic with AIC (-48.07534), BIC (-38.83112) and RMSE (0.2058) and lastly the Constant form factor model with AIC (-47.70249), BIC (-41.53968) and RMSE (0.2067). From the result, the combined variable was chosen as the best fit and was used to construct the volume table for *Pinus caribbaea.* All the models used for this study were based on two variables (DBH and total height). It was noted that [6] compared models based on one variable (DBH or H) and models based on two variables (DBH and H) and based on the findings, the models consisting of two variables was found to have the least standard error (10.3) and highest Adjusted $R^{2}$ (0.982) and hence found to be the best.

Table 3 Volume Models for *Pinus caribbaea*

|  |  |  |  |
| --- | --- | --- | --- |
| **S/N** | **Models**  | **Regression parameters**  | **Fit indices** |
| 1 | Combined variable | $b\_{0}$= -9.857e-02$b\_{1}$= 3.851e-05 | AIC= -54.73395BIC= -45.48974RMSE= 0.2016 |
| 2 | Constant form factor | $b\_{1}$= 3.540e-05 | AIC= -47.70249BIC=-41.53968RMSE= 0.2067 |
| 3 | Logarithmic | $b\_{0}$= -11.8963$b\_{1}$= 1.4826 | AIC= -48.07534BIC= -38.83112RMSE= 0.2058 |
| 4 | Generalized combined variable | $b\_{0}$= 3.352e-01$b\_{1}$= -4.859e-04$b\_{2}$= -1.547e-02$b\_{3}$=5.542e-05 | AIC= -54.09115BIC= -38.68413RMSE= 0.2008 |
| 5 | Generalized logarithmic | $b\_{0}$= 3.352e-01$b\_{1}$= -4.859e-04$b\_{2}$= -1.547e-02$b\_{3}$= 5.542e-05 | AIC= -54.09115BIC= -38.68413RMSE= 0.2008 |

AIC= Akaike information criterion, BIC= Bayesian information criterion, RMSE= Root Mean square error, $b\_{0}, b\_{1}, b\_{2}, b\_{3}$ are regression parameters

**3.1 Volume Table**

After fitting the selected volume models on the *Pinus caribbaea* data set and subjecting them to the required selection indices which are Akaike information criterion (AIC), Bayesian information criterion (BIC) and Root Mean square error (RMSE), the Combined variable model, with the least AIC (-54.73395), BIC (-45.48974) and RMSE (0.2016) was selected as the best fit and was used to construct the volume table. Also, the measured and estimated volume were compared using correlation graph (Figure 3).

The models used in this study were similar to the models used by [18] to estimate the volume of *Tectona grandis* stands in Nnamdi Azikiwe University, Awka, Nigeria. The result from this study disagrees with the work from [5] who used the Logarithmic volume model to develop the volume table for *Pinus caribaea* in Bulolo Wau forest plantations of Papua New Guinea. The Logarithmic model was found suitable based on the data and has Adjusted $R^{2}$ of 0.957 which means that the volume estimation of *Pinus Carribeae* using the derived volume equation will be 95.7% closer to the exact volume. The disagreement might be as a result of differences like site quality or stand age among other factors. In order to confirm the validity of using these equations, residual analysis was conducted as pointed out by [19], and the results revealed a strong positive correlation (Figure 3) between the volumes obtained from Newton’s equation and the selected volume model. The developed volume table is presented in Table 4 using the selected model:

 $V\_{i}=-9.857e-02+3.851e-05D\_{i}^{2}H\_{i}+ε\_{i}$

Figure 3 Correlation between measured and estimated volume for *P. Caribbaea*

Table 4. Volume Table for *Pinus Caribaea* (est. 1997)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dbh(cm)** | **H(m)** | **V (**$m^{3})$ | **Dbh(cm)** | **H(m)** | **V (**$m^{3}$**)** | **Dbh(cm)** | **H(m)** | **V (**$m^{3}$**)** |
| 18.4 | 29.5 | 0.286049 | 27.4 | 17.3 | 0.401604 | 39.8 | 30 | 1.731471 |
| 33.2 | 28.2 | 1.098443 | 20.3 | 12.3 | 0.096626 | 41.1 | 31.6 | 1.957057 |
| 24.3 | 27.9 | 0.53587 | 32.8 | 30 | 1.144348 | 32 | 31.5 | 1.143609 |
| 39.1 | 30.1 | 1.673552 | 28.4 | 28.2 | 0.77734 | 40.7 | 29 | 1.751381 |
| 22.5 | 29.7 | 0.480452 | 40.8 | 32.1 | 1.95921 | 32.1 | 30.5 | 1.111703 |
| 27.9 | 26.1 | 0.683818 | 29.3 | 29.4 | 0.873407 | 23.1 | 25 | 0.415163 |
| 23.5 | 26.9 | 0.473516 | 23.3 | 28.3 | 0.493089 | 32.7 | 30.5 | 1.15737 |
| 27.6 | 31.1 | 0.81376 | 25.7 | 29.9 | 0.661951 | 16.7 | 22.4 | 0.142007 |
| 25.6 | 30.2 | 0.663615 | 26.2 | 28.7 | 0.660109 | 27 | 23.6 | 0.563971 |
| 22 | 17.2 | 0.222018 | 25.5 | 28.9 | 0.625119 | 30.6 | 28.2 | 0.9183 |
| 31 | 29.5 | 0.993169 | 29.4 | 27.4 | 0.81348 | 25.5 | 25.8 | 0.547491 |
| 29.4 | 27.3 | 0.810152 | 25.5 | 27.2 | 0.582549 | 17.1 | 10.6 | 0.020794 |
| 17.2 | 17.5 | 0.100804 | 42.1 | 30.1 | 1.955921 | 40 | 30.6 | 1.78688 |
| 25.7 | 30 | 0.664494 | 23.9 | 20.6 | 0.354574 | 38.5 | 30.9 | 1.665247 |
| 40.3 | 32.2 | 1.915337 | 24.5 | 26.6 | 0.516306 | 25.9 | 30.7 | 0.6945 |
| 40.7 | 32.3 | 1.961893 | 44.5 | 31.9 | 2.334106 | 39.4 | 30.9 | 1.748675 |
| 22.9 | 28.2S | 0.47093 | 26.3 | 27.1 | 0.623292 | 32.3 | 30.6 | 1.130849 |
| 22.5 | 17.4 | 0.240655 | 18.2 | 20.1 | 0.157827 | 28.9 | 30.2 | 0.872781 |
| 26.2 | 29.9 | 0.691831 | 22.5 | 30.7 | 0.499948 | 25 | 32.6 | 0.686071 |
| 40.5 | 33.1 | 1.992226 | 27.2 | 28.8 | 0.721978 | 52 | 30.1 | 3.035774 |
| 25.4 | 27.9 | 0.594609 | 31.7 | 30.2 | 1.070119 | 35 | 28.5 | 1.24591 |
| 25.4 | 28.9 | 0.619454 | 24.8 | 30.6 | 0.626197 | 22 | 17.7 | 0.231337 |
| 19.4 | 17.1 | 0.149271 | 18.9 | 32.1 | 0.343003 | 34.4 | 30.7 | 1.300466 |
| 19 | 16.8 | 0.134985 | 24 | 28.9 | 0.542483 | 22.9 | 27.8 | 0.462852 |
| 36.3 | 30.7 | 1.459278 | 24.9 | 28.6 | 0.5843 | 24.5 | 30.1 | 0.59721 |
| 29.1 | 30.6 | 0.899316 | 29 | 28.9 | 0.837412 | 42.3 | 30 | 1.968597 |
| 20.4 | 29.8 | 0.379014 | 33.8 | 25 | 1.001314 | 42.3 | 30 | 1.968597 |
| 30.6 | 28.9 | 0.943542 | 36 | 25 | 1.149154 | 21.6 | 26.9 | 0.384748 |
| 35.3 | 32 | 1.437012 | 21.3 | 26.3 | 0.360933 | 22.6 | 26.9 | 0.430536 |
| 27.4 | 31.4 | 0.80926 | 26.7 | 26.7 | 0.634436 | 29.6 | 28.5 | 0.863046 |
| 21.6 | 28.9 | 0.420683 | 26.4 | 28.6 | 0.669052 | 39.8 | 30.1 | 1.737572 |
| 26.4 | 30.7 | 0.725416 | 29.6 | 30.1 | 0.917032 | 28.3 | 29.9 | 0.823614 |
| 29.3 | 30.6 | 0.91308 | 42.6 | 31.6 | 2.10984 | 39.3 | 30.5 | 1.715518 |
| 26.4 | 29.5 | 0.693208 | 21 | 31.1 | 0.429599 | 34.7 | 26.9 | 1.14877 |
| 27.5 | 30.1 | 0.778038 | 38.8 | 32.2 | 1.768209 | 25.5 | 26.7 | 0.570028 |
| 23.9 | 30.3 | 0.567948 | 29.9 | 31.9 | 0.999694 | 23.2 | 26.7 | 0.454858 |
| 26.6 | 28.9 | 0.688901 | 29.3 | 29.9 | 0.889937 | 22.6 | 27.9 | 0.450205 |
| 22.6 | 28.9 | 0.469875 | 29.9 | 30 | 0.93428 | 26.1 | 28.1 | 0.638588 |
| 22.6 | 30.1 | 0.493478 | 31.7 | 30.6 | 1.085598 | 23.9 | 30 | 0.561349 |
| 23.2 | 30.3 | 0.529477 | 23.1 | 31 | 0.538459 | 31.5 | 30.1 | 1.051598 |
| 31.5 | 30.5 | 1.066882 | 22 | 30.7 | 0.473642 | 27.7 | 29.9 | 0.784925 |
| 22.3 | 28.6 | 0.449138 | 22 | 30.7 | 0.473642 | 26.4 | 30.1 | 0.709312 |
| 29 | 28.8 | 0.834173 | 24.7 | 28.6 | 0.573375 | 37.6 | 31 | 1.589191 |
| 21 | 25.8 | 0.339589 | 31.6 | 30.5 | 1.074294 | 31.2 | 31 | 1.063532 |
| 39.1 | 32 | 1.785413 | 32 | 30.2 | 1.092344 | 29.3 | 30.1 | 0.89655 |
| 18.1 | 20.9 | 0.16511 | 31.6 | 30.3 | 1.066603 | 17.2 | 29.8 | 0.240935 |
| 24.8 | 30.5 | 0.623828 | 29.8 | 30.6 | 0.947902 | 33.4 | 31.2 | 1.241789 |
| 30.2 | 30.8 | 0.983208 | 22.9 | 29.9 | 0.505261 | 39.5 | 31.6 | 1.800123 |
| 33.7 | 30.6 | 1.239734 | 28.6 | 29.6 | 0.833819 | 39.5 | 31.6 | 1.800123 |
| 21 | 28.9 | 0.392236 | 32.5 | 30 | 1.121716 | 24.5 | 30.6 | 0.608768 |

**4. CONCLUSION**

The volume table developed will be useful in giving an estimate of the quantity of wood or timber available in the *Pinus Caribaea* plantation at a given time and can also help managers to monetize their plantations. The volume model and local volume table developed is to be applied on the *Pinus Caribaea* plantation in the study area only. Finally, it is suggested that researchers work on some other species in area J4 and other locations to prepare more comprehensive volume tables.

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